POWER-OFF NOISE SUPPRESSION CIRCUIT AND ASSOCIATED METHODS FOR AN AUDIO AMPLIFIER DEVICE

Field of the Invention

The present invention relates to the field of electronics, and, more particularly, to an audio amplifier device.

Background of the Invention

In some power supplies, the supply voltage V_{CC} power-off time is fairly long. The rate of decrease from V_{CC} to 0 depends on the capacitive and inductive load of the power supply. A typical power-off time for a power supply providing a supply voltage to a sound card in a computer system or cellular telephone is about 120 ms to go from 12 to 0.5 volts, for example. A problem associated with such an audio amplifier is a loud popping noise generated by the amplifier as the supply voltage is switched-off.

One approach to reduce or minimize power-off noise will now be discussed with reference to FIG. 1. A Class B audio amplifier **20** is connected to a 12 volt power supply **22**. The audio amplifier **20** includes an input for receiving an audio input signal V_I and an output for providing an amplified audio output signal

V_{OUT}. A speaker **24** is connected to the output of the audio amplifier **20**.

The audio amplifier **20** typically includes a supply voltage rejection circuit **28** (FIG. 2) for suppressing noise from the power supply **22**. The audio amplifier **20** thus includes an input for receiving a supply voltage rejection signal V_{SVR} for the supply voltage rejection circuit. The capacitors C_{IN}, C_P, C_S and C_{OUT} are external capacitors to the audio amplifier **20**. To reduce the power-off noise heard at the speaker **24**, transistors Q1 and Q2 are connected to the power supply **22**, to the input of the audio amplifier **20** receiving the supply voltage rejection signal V_{SVR}, and to the output of the audio amplifier providing the amplified audio output signal V_{OUT}.

The transistor Q1 includes a base terminal connected to the power supply **22**, a collector terminal connected to the base terminal of transistor Q2, and an emitter terminal connected to the input of the audio amplifier **20** receiving the supply voltage rejection signal V_{SVR}. Transistor Q2 includes a collector terminal connected to the output of the amplifier **20**, and an emitter terminal connected to a voltage reference, such as ground. When a rate of decrease of the supply voltage rejection signal V_{SVR} is greater than a rate of decrease of the supply voltage V_{CC}, i.e., $V_{SVR} > V_{CC}$, transistors Q1 and Q2 are turned on. This causes the output of the amplifier **20** to be shorted and the output noise is thus minimized.

However, when the supply voltage V_{CC} does not decrease as fast as the supply voltage rejection signal V_{SVR}, i.e., $V_{CC} > V_{SVR}$, transistors Q1 and Q2 will not be turned on. The supply voltage rejection circuit **28** of the amplifier **20** is still active. When the supply

voltage V_{CC} is larger than V_{SVR} by 1 to 2 times the conducting voltage V_{be} for at least one transistor Q3 within the supply voltage rejection circuit **28,** transistor Q3 is saturated. Transistor Q3 and other portions of the supply voltage rejection circuit **28** are best illustrated with reference to FIG. 2.

Referring now to FIG. 3a, a graph illustrating a rate of decrease of the supply voltage V_{CC}, the supply voltage rejection signal V_{SVR}, and the audio output signal V_{OUT} at power-off of the power supply **22** is provided. As discussed above, when the supply voltage V_{CC} is larger than V_{SVR} by 1 to 2 times the conducting voltage V_{be} for transistor Q3 within the supply voltage rejection circuit **28,** transistor Q3 is saturated.

When transistor Q3 is saturated during power-off, ripples present in the power supply **22** are fed into the supply voltage rejection circuit **28** and amplified by transistors Q4 and Q5. As a result, the loud popping noise during power-off can be heard at the output of the amplifier **20** via the speaker **24** connected thereto. FIG. 3b is an expanded graph of the audio output signal V_{OUT} illustrated in FIG. 3a to highlight the noise present during power-off of the power supply **22.** An audio amplifier that is not associated with this popping characteristic is thus desirable.

Summary of the Invention

In view of the foregoing background, it is an object of the present invention to minimize or reduce audio amplifier noise during power-off.

This and other objects, features and advantages in accordance with the present invention are provided by an audio amplifier device comprising a

power supply including an output for providing a supply voltage, and a voltage divider connected to the output of the power supply for providing a divided supply voltage, and an audio amplifier. The audio amplifier preferably comprises a supply voltage rejection circuit and includes a first input for receiving an input audio signal, a second input for receiving the supply voltage, a third input for receiving a supply voltage rejection signal for the supply voltage rejection circuit, and an output for providing an output audio signal. A speaker is preferably connected to the output of the audio amplifier.

The audio amplifier device preferably further comprises a power-off noise suppression circuit having a first input for receiving the divided supply voltage and an output for providing the supply voltage rejection signal. The power-off noise suppression circuit preferably sets the supply voltage rejection signal equal to the divided supply voltage during power-off of the power supply so that a rate of decrease of the supply voltage is greater than a rate of decrease of the supply voltage rejection signal for reducing noise in the output audio signal during the power-off.

Because the supply voltage rejection signal is set equal to the divided supply voltage during power-off, the rate of decrease of the supply voltage is maintained so that it is greater than the rate of decrease of the supply voltage rejection signal. This advantageously prevents at least one transistor in the supply voltage rejection circuit from being saturated. Saturation of this transistor causes the popping noise to be heard at the output of the speaker during power-off of the power supply.

In one embodiment, the power-off noise suppression circuit includes a second input connected to the output thereof so that the power-off noise suppression circuit is configured as a voltage follower. The power-off noise suppression circuit preferably comprises a pair of first and second transistors each comprising a first conduction terminal connected to the power supply.

The first transistor preferably comprises a control terminal connected to the first input of the power-off noise suppression circuit, and the second transistor comprises a control terminal connected to the third input of the audio amplifier for providing the supply voltage rejection signal. A switch is preferably connected to the pair of first and second transistors and is operated when the divided supply voltage is greater than the supply voltage rejection signal during power-off so that the supply voltage rejection signal is set equal to the divided supply voltage. In one embodiment, the switch preferably comprises a transistor.

Another aspect of the invention relates to a method for reducing noise in an output audio signal during power-off of an audio amplifier device comprising an audio amplifier that includes an amplifier and a supply voltage rejection circuit. The audio amplifier device includes a first input for receiving an input audio signal, a second input for receiving a supply voltage, a third input for receiving a supply voltage rejection signal for the supply voltage rejection circuit, and an output for providing the output audio signal.

The method includes turning off the power supply for powering-off the audio amplifier device, and dividing the supply voltage into a divided supply

voltage. The method further includes setting the supply voltage rejection signal equal to the divided supply voltage during power-off so that a rate of decrease of the supply voltage is greater than a rate of decrease of the supply voltage rejection signal.

Brief Description of the Drawings

FIG. 1 is a schematic diagram of an audio amplifier with an external pair of transistors for minimizing noise during power-off of the power supply in accordance with the prior art;

FIG. 2 is a schematic diagram of a supply voltage rejection circuit that is internal to the audio amplifier illustrated in FIG. 1;

FIG. 3a is a graph illustrating the supply voltage, the supply voltage rejection signal and the audio output signal at power-off of the power supply in accordance with the prior art;

FIG. 3b is an expanded graph of the audio output signal illustrated in FIG. 3a to highlight the noise present during power-off of the power supply;

FIG. 4 is a schematic diagram of an audio amplifier device with a power-off noise suppression circuit in accordance with the present invention;

FIG. 5 is a schematic diagram of the power-off noise suppression circuit illustrated in FIG. 4;

FIG. 6a is a graph illustrating the supply voltage, the divided supply voltage, the supply voltage rejection signal and the audio output signal at power-off of the power supply in accordance with the present invention; and

FIG. 6b is an expanded graph of the audio output signal illustrated in FIG. 6a to highlight the noise present during power-off of the power supply.

Detailed Description of the Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The dimensions of layers and regions may be exaggerated in the figures for greater clarity.

Referring initially to FIG. 4, an audio amplifier device **40** with a power-off noise suppression circuit **42** in accordance with the present invention will now be described. The audio amplifier device **40** comprises a power supply **22** including an output for providing a supply voltage V_{CC}, and a voltage divider connected to the output of the power supply for providing a divided supply voltage V_A. The voltage divider may be formed by two resistors R_1 and R_2, for example.

The audio amplifier device **40** also comprises an audio amplifier **44** that includes an amplifier **46** and a supply voltage rejection circuit **28**. The audio amplifier **46** is a Class B amplifier, for example, as readily understood by one skilled in the art. A speaker **24** is connected to the output of the audio amplifier **44**.

The audio amplifier **44** includes a first input for receiving an input audio signal V_I, a second input for receiving the supply voltage V_{CC}, a third input for

receiving a supply voltage rejection signal V_{SVR} for the supply voltage rejection circuit **28**, and an output for providing an output audio signal V_{OUT}.

The audio amplifier device **40** further includes the power-off noise suppression circuit **42** having a first input for receiving the divided supply voltage V_A and an output for providing the supply voltage rejection signal V_{SVR}. The power-off noise suppression circuit **42** sets the supply voltage rejection signal V_{SVR} equal to the divided supply voltage V_A during power-off of the power supply **22** so that a rate of decrease of the supply voltage V_{CC} is greater than a rate of decrease of the supply voltage rejection signal for reducing noise in the output audio signal V_{OUT} during the power-off.

As discussed above, the supply voltage rejection circuit **28** includes at least one transistor Q3 that is saturated when the supply voltage V_{CC} does not decrease as fast as the supply voltage rejection signal V_{SVR}. This results in the popping noise being heard through the speaker **24** during power-off, as best illustrated with reference to FIG. 3b.

Powering-off of the power supply **22** thus sets equal the supply voltage rejection signal V_{SVR} to the divided supply voltage V_{CC} so that the rate of decrease of the supply voltage is maintained so that it is greater than the rate of decrease of the supply voltage rejection signal. This advantageously prevents transistor Q3 in the supply voltage rejection circuit **28** from being saturated. Saturation of transistor Q3 causes the popping noise to be heard at the output of the speaker **24** during power-off of the power supply **22**.

In one embodiment, the power-off noise suppression circuit **42** includes a second input

connected to the output thereof so that the power-off noise suppression circuit is configured as a voltage follower. The power-off noise suppression circuit **42** comprises a pair of first and second transistors Q8 and Q9 connected together. As illustrated in FIG.5, the pair of first and second transistors Q8 and Q9 are PNP transistors, for example.

Each of these transistors includes a first conduction terminal connected in common to the power supply **22**. The first transistor Q9 comprises a control terminal connected to the first input of the power-off noise suppression circuit **42**, and the second transistor Q8 comprises a control terminal connected to the third input of the audio amplifier **44** for providing the supply voltage rejection signal V_{SVR}.

A switch Q10 is connected to the pair of first and second transistors Q8 and Q9 and is operated when the divided supply voltage V_A is greater than the supply voltage rejection signal V_{SVR} during power-off so that the supply voltage rejection signal is set equal to the divided supply voltage. As illustrated in FIG. 5, the switch Q10 may be a transistor, such as an NPN transistor, for example. The power-off noise suppression circuit **42** further comprises a bias circuit R3 connected to the switch Q10. This bias circuit R3 may be a resistor, for example.

As discussed above, the power-off noise suppression circuit **42** includes a second input connected to the output thereof so that the power-off noise suppression circuit may be configured as a voltage follower. In this way, the power-off noise suppression circuit **42** can force $V_{SVR} = V_A$. With respect to the voltage divider providing the divided supply voltage V_A, and assuming that $R_2 = K * R_1$, then

$$V_A = \frac{K \times V_{CC}}{K+1}$$

When the power supply **22** is switched off, the divided supply voltage V_A goes down with the power supply V_{CC} until $V_A = V_{SVR}$, as best shown in FIG. 6a. Then the supply voltage rejection voltage V_{SVR} will follow the divided supply voltage V_A. Hence:

$$V_{CC} - V_{SVR} = V_{CC} - \frac{K \times V_{CC}}{K+1} = \frac{V_{CC}}{K+1}$$

An appropriate K can be selected such that

$$\frac{V_{CC}}{K+1} > 2V_{be}$$

and, hence transistor Q3 is kept out of saturation. The rate of decrease of the supply voltage V_{CC} is preferably greater than the rate of decrease of the supply voltage rejection signal V_{SVR} by at least the conducting voltage of transistor Q3. Consequently, ripples present in the power supply **22** cannot feed into the supply voltage rejection circuit **28**, and the audible noise at the output can be minimized, as best shown in FIG. 6b.

Another aspect of the invention relates to a method for reducing noise in an output audio signal V_{OUT} during power-off of an audio amplifier device **40** comprising an audio amplifier **44** that includes an amplifier **46** and a supply voltage rejection circuit **28**. The audio amplifier device **40** includes a first input for receiving an input audio signal V_I, a second input for receiving a supply voltage V_{CC}, a third input for receiving a supply voltage rejection signal V_{SVR} for the

supply voltage rejection circuit **28**, and an output for providing the output audio signal V_{OUT}.

The method includes turning off the power supply **22** for powering-off the audio amplifier device **40**, and dividing the supply voltage V_{CC} into a divided supply voltage V_A. The method further includes setting the supply voltage rejection signal V_{SVR} equal to the divided supply voltage V_A during power-off so that a rate of decrease of the supply voltage V_{SVR} is greater than a rate of decrease of the supply voltage rejection signal.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.